Evaluating the true cost of methyl bromide fumigation and debarking for log exports out of Marsden Point

A dissertation submitted in partial fulfilment of the requirements for the degree of Bachelor of Forestry Science with Honours by:

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Abstract

Over half of New Zealand's annual harvest was exported as logs to four markets in 2015: China (68%), Korea (17%), India (11%) and Japan (3%). All of the deck cargo currently exported out of Marsden Point to India, as well as the majority of Chinese cargo, is fumigated with methyl bromide in order to meet phytosanitary requirements. The remaining proportion of Chinese deck cargo is debarked. Exports to Korea and Japan are treated on arrival. If the 2020 deadline set by the Environmental Protection Authority (which requires that all methyl bromide must be recaptured or destroyed following fumigation) cannot be met, then alternative methods will be needed to meet phytosanitary requirements. Debarking is an alternative method that could be used instead of methyl bromide for Chinese exports, whilst Indian exports would have to cease due to a lack of approved alternative treatment methods.

Several factors were identified that influence the cost of debarking operations, including: debarker specifications, resource availability, production mix, shipping load improvements, bark disposal, land lease, additional handling and transport, power, maintenance, and staffing costs.

When all suitable log grades were included in the production mix (Pruned, Small-Pruned, A-Grade, A-Oversize, and K-Grade logs), it was found that the entire volume of wood in Northland that is forecasted to be exported as deck cargo (960,400m^3), from 2020 onwards, could be debarker using a Nicholoson A5C 27" ring debarker. The average cost expected for debarking this volume was calculated at \$2.52/JAS m^3. When broken down by log grade it was found that A-Oversize and Pruned logs were the cheapest to debark, at a cost of \$1.09/JAS m^3; followed by A-Grade and Small-Pruned logs at \$1.84/JAS m^3; and K-Grade logs at \$3.86/JAS m^3. Despite the high cost of debarking K-Grade logs it was found to be \$0.46/JAS m^3 cheaper to include them in the production mix due to increased economies of scale. As China is the only country that currently approves debarking as a phytosanitary treatment it would be logical to only debark Chinese bound cargo. If this was to occur, it is expected the average debarking rate would increase to \$2.88/JAS m^3 due to reduced economies of scale.

Additional handling and transport costs were the most significant factor influencing debarking costs, accounting for 71% of the overall cost. Capital cost was the next most important factor, accounting for 16% of overall costs, followed by maintenance (11%), shipping load improvements (-10%), staff (6%), power (5%), and land lease costs (1%). The base case model assumed that there would be no cost or revenue resulting from bark disposal. However, if a price, or a revenue, of \$20/m^3 was imposed for disposal, then a 37% change in the average debarking cost would be expected.

When compared to the true cost of methyl bromide fumigation at Marsden Point, which was calculated at \$5.25/JAS m^3 (in June 2017 dollars), debarking appears to be an economically favourable method for meeting phytosanitary requirements.

Keywords: *methyl bromide, fumigation, debarking, phytosanitary, Marsden Point, forestry, log, exports.*

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1. Introduction

Logs exports are a major component of the New Zealand forestry industry. In 2015 log exports accounted for 52%, 15.4 million cubic metres, of the 29.6 million cubic metres harvested. The total value of log exports in 2015 was worth 1.9 billion dollars, 42% of the 4.7 billion dollar value of all forest product exports.

A requirement of log exporters is to ensure compliance with the phytosanitary standards set by importing countries. One of the methods used to meet the phytosanitary standards set by these countries is to fumigate logs with methyl bromide. However, a 2010 decision by the New Zealand Environmental Protection Authority (previously the Environmental Risk Management Authority) determined that any methyl bromide used for phytosanitary purposes from 2020 onwards will need to be either recaptured or destroyed, rather than released to the atmosphere.

At present, the technologies needed to recapture or destroy methyl bromide are not currently viable, and may not be by 2020 (Armstrong, Brash, & Waddell, 2014; Armstrong, et al., 2014; Gifford Consulting, 2015). Accordingly, research is needed to evaluate alternative phytosanitary treatments. Debarking is an alternative phytosanitary treatment method which is already approved for Chinese markets, but not for India. As such, it is possible that debarking could provide a solution to meeting importing countries phytosanitary requirements, should the use of methyl bromide not be viable from 2020.

The aim of this research is to evaluate the true cost of methyl bromide fumigation and compare it with the true cost of debarking for log exporting operations out of Marsden Point.

2. Problem statement

In order to meet the 2020 deadline set by the New Zealand Environmental Protection Agency (EPA) it is imperative that alternative phytosanitary treatment methods are explored. One such alternative is the use of debarking.

To assess the economic feasibility of debarking versus methyl bromide fumigation a detailed costing analysis is needed to compare the two processes. If it is found that debarking is economically competitive compared to methyl bromide fumigation it could be used on a large scale to meet the phytosanitary requirements of some importing countries.

As each port has a unique environment, operating parameters, and constraints, it may be necessary to study each port individually. For the purpose of my dissertation I will be focusing on log exports out of Marsden Point to analyse the true cost of fumigation versus debarking.

2.1 Research questions

To evaluate whether or not debarking is an economically viable alternative to methyl bromide fumigation at Marsden Point the following questions will need to be answered:

- What are the current phytosanitary measures in place at Marsden Point, and how may these practices change if methyl bromide use is no longer permissible?
- What are the factors affecting the cost of debarking export logs at a scale appropriate to export operations at Marsden Point?
- What is the expected debarking cost per JAS m^3, and how does this compare to current methyl bromide fumigation practices?

3. Background

3.1 Importing countries phytosanitary requirements

As a requirement of our trading partners, log exports must be treated to a standard determined by the importing country in order to minimise the risk of incursions and the establishment of unwanted organisms. Of the 15.4 million cubic metres of logs exported in 2015, 99% of the total volume was destined to four markets: China (68%), Korea (17%), India (11%), and Japan (3%) (Ministry for Primary Industries [MPI], 2016).

The importing countries phytosanitary requirements for these markets are shown in Table 1; apart from Korean and Japanese markets, which do not require exporters to treat logs as fumigation occurs on arrival of the importing country at the customers cost (Ministry for Primary Industries, 2017). Despite heat treatment being an approved method for Indian exports there are currently no technically or economically viable systems to treat logs on a large scale. As such, all log exports to India are required to be treated with methyl bromide.

Of the 13 million cubic metres of logs exported to China and India in 2015 approximately 3.7 million cubic metres required treatment with methyl bromide. Of this volume, 1.4 million cubic metres was destined to Indian markets and the remaining 2.3 million cubic metres was exported to Chinese markets (Ministry for Primary Industries, 2016; STIMBR, 2017). The remaining Chinese bound logs were treated with phosphine (8.4 million cubic metres) or debarked (0.96 million cubic metres).

Table 1: Importing countries phytosanitary requirements (Ministry for Primary Industries, 2017)

Importing Country	Approved Pre-Shipment Treatments
China	Methyl bromide fumigation rates: • $80 g/m^3$ for a minimum of 16 hours and ambient temperature above 15^oC • $120 g/m^3$ for a minimum of 16 hours and ambient temperatures between 5^oC to 15^oC In-hold Phosphine fumigation rate: • Minimum $2g/m^3$ initially with top up of $1.5g/m^3$ required after 5 days. Minimum gas concentration of 200ppm must be maintained for 10 days within sealed holds Debarking • No more than 5% bark on any individual log • No more than 2% bark on any consignment of logs

India	Methyl bromide fumigation rates: • $48 g/m^3$ at an ambient temperature at least 21ºC or above for 24 hours • $56 g/m^3$ at ambient temperatures between 16 – 20ºC for 24 hours • $64 g/m^3$ at ambient temperatures between 11 – 15ºC for 24 hours • $72 g/m^3$ at ambient temperatures between 10 – 11ºC for 24 hours Heat treatments: • Core temperature of wood must be at least 56ºC for 30 minutes

3.2 Marsden Point export operations

Marsden Point, near Whangarei, is home to Northport - New Zealand's northern most deep-water port (Figure 1). Northport has on port (tent) methyl bromide fumigation capabilities as well as a debarking and anti-sapstain plant capable of processing up to 350,000 tonnes of logs per year (Universal Engineering Limited, 2017). Adjacent to the port boundary is 180 hectares of undeveloped commercially zoned land (Northport, 2017) which could potentially be used to house a large-scale debarking plant.

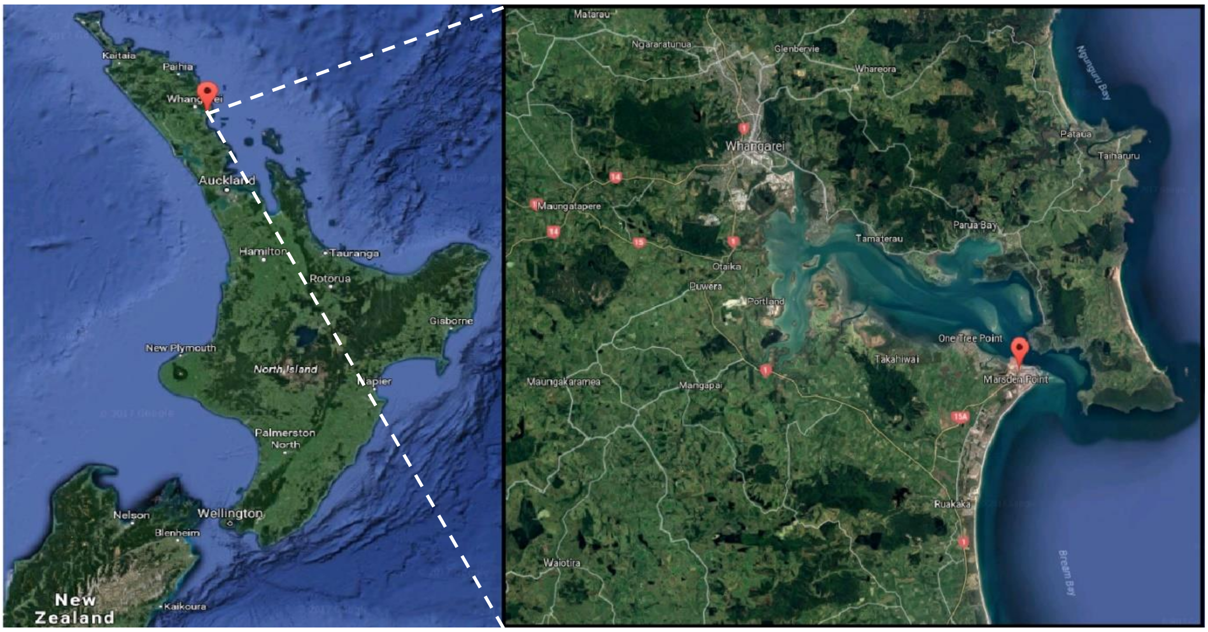

Figure 1: Location of Marsden Point

Northport is primarily used for ‘topping up’ vessels. This means that vessels arrive from other ports (typically Gisborne, Tauranga or Napier) requiring deck cargo and sometimes a small proportion of hold cargo. The average export log vessel payload is approximately 30,000 JAS m^3; 20,000 JAS m^3 of which is loaded in the hold and the remaining 10,000 JAS m^3 is stowed on deck.

Northport is the closest port to our major export markets and in 2015 exported 2.6 million cubic metres of logs, 16% of the of 16 million cubic metres harvested nationwide (Ministry for Primary Industries, 2016). Current phytosanitary practices at Northport involve on port tent fumigation with methyl bromide for the majority deck cargo, with a very small remaining proportion made up of debarked logs. All hold cargo destined to Chinese markets is treat in transit with phosphine, and all Indian bound cargo is treated with methyl bromide.

3.3 Methyl bromide

3.3.1 Chemical properties

Methyl bromide, or bromomethane (CH_3Br), is an organic brominated hydrocarbon that is produced from natural and anthropogenic sources. Known sources of methyl bromide emissions include: oceanic emissions, biomass burning, emissions from leaded petrol, and emissions resulting from fumigation. In total, global emissions are believed to be between 100 – 200 million kilograms per year. Emissions from industrial uses are expected to account for between 20 – 65% of total emissions (Butler, 1995).

The low boiling point of methyl bromide, $4.0^{O}C$, means that the compound is gaseous at typical New Zealand temperatures and atmospheric pressures. The compound is colourless in liquid and gaseous forms, and is imported as a pressurised liquid in metal cylinders from the United States (Envrionmental Risk Managment Authority, 2010). As a gas, methyl bromide diffuses rapidly as separate molecules, quickly penetrating into the materials being fumigated. Following fumigation the gas rapidly desorbs and dissipates into the atmosphere. Due to the rapid desorption and dissipation that follows post treatment, the use of methyl bromide allows relatively safe handling of materials post fumigation (Ministry for Primary Industries, n.d).

Methyl bromide has a slight aromatic odour in high concentrations – similar to chloroform. At low concentrations the gas is odourless, but can still be toxic. It is a poorly inflammable gas and can form explosive mixtures with air at between 8.6% and 20% by volume. However, methyl bromide requires a very high energy ignition source (at least $535^{O}C$) for combustion to occur. The volume required to form an explosive mixture and the high ignition temperature effectively making methyl bromide a non-flammable and non-explosive under standard operating conditions. The gas has a specific gravity of 3.97kg/m^3, which is slightly more than 3 times the density of air, 1.29 kg/m^3. As such, methyl bromide can accumulate in poorly ventilated or low-lying areas, which poses a health risk (IFA, 2017; Ministry for Primary Industries, n.d).

The insecticidal value of methyl bromide was first report by Le Goupil (1932) in France and since then it has been widely used to control insect pests, nematodes, weeds, pathogens and rodents. Methyl bromide has generally been acknowledged as the 'gold standard' of pesticides for agricultural and quarantine uses because of its properties. It is to a large extent irreplaceable due to the declining number of chemical fumigants approved for use – due to health and safety and environmental concerns (Bond, 1984). However, methyl bromide usage is not exempt from health and safety and environmental concerns and is currently in the process of being phased out.

3.3.2 Environmental impacts

Approximately 25 kilometres above the surface of the earth is an ozone layer within the stratosphere. A vital function of the ozone layer is to reduce of the incidence of ultraviolet rays (UV-B) emitted by the sun from reaching the surface of the earth. UV-B rays have many detrimental effects on living organisms, including marine life, crops, animals, birds and humans. For humans, UV-B rays are known to: increase likelihood of melanoma skin cancers, cause eye damage (including cataracts), cause damage to the immune system, and increase susceptibility to diseases such as malaria (World Bank Group, 1998).

In addition to detrimental effects to living organisms, UV-B exposure can have negative effects on a plethora of materials due to photochemical reactions and heat. Exposure over prolonged periods of time can cause photo-degradation of organic and synthetic materials through photolysis, photo-oxidation and other process; potentially resulting in equipment problems, fire hazards, and increased maintenance costs (Kowalski, 2009). Materials often damaged by UV-B exposure include: paints, varnishes, textiles, wood, and plastic polymers (polyurethane, polycarbonates, polyvinyl chloride, polystyrene, polypropylene, etc.).

Halogenated hydrocarbons (molecules consisting of carbon, and at least one fluorine, chlorine, iodine or bromine atoms) have been added to the natural environment in increasing quantities over past decades. Additions to the atmosphere have primarily resulted from the use of aerosol propellants, refrigerants and fumigants. An unintended consequence of using halogenated hydrocarbons is that over time the compounds diffuse up into the stratosphere. Once the compounds reach the stratosphere they are broken down by solar radiation, resulting in an extensive catalytic chain reaction that leads to the net destruction of ozone (Molina & Rowland, 1974; Mellouki, et al., 1992).

The concept of Ozone Depletion Potential (ODP) has since been introduced to compare the impact of various halocarbons on the stratospheric ozone layer. An ODP value represents the amount of ozone that will be destroyed over the life cycle of the halocarbon, relative to the quantity of ozone destroyed by one kilogram of trichloroflouromethane, CFC-11 (Selywn, Georges, & Georgiev, 1997).

Methyl bromide released into the atmosphere is believed to be the principal source of stratospheric bromine, which is extremely effective in converting ozone to oxygen. On a per atom basis, bromine is approximately 50 times more effective than chlorine in destroying ozone. Methyl bromide has an ODP of 0.65, meaning that it is not as destructive as CFC-11. It is expected that reactions involving bromine are responsible for 20 – 25% of the 'ozone hole' above the Antarctic. The reason for this is that methyl bromide reaches the stratosphere and breaks down much faster than CFC-11. The approximate half-life for each compound are less than 1 year and around 55 years respectively. As methyl bromide has a short life span any emissions have a rapid influence in the quantity of ozone present. Conversely, ozone reductions due to CFC-11 emissions will be realised until 55 years after the gas has been released into the atmosphere (Mellouki, et al., 1992; Butler, 1995).

In addition to ozone depletion, methyl bromide is also a greenhouse gas. In 2007, the Intergovernmental Panel on Climate Change reported that methyl bromide has a global warming potential 17 times greater than carbon dioxide over a 20-year timeframe (Solomon, et al., 2007).

Due to the realisation that the use of halogenated hydrocarbons will result in the destruction of ozone the Montreal Protocol was established in 1987 in order "to protect the ozone layer by taking precautionary measures to control equitably total global emissions of substances that deplete it, with the ultimate objective of their elimination on the basis of developments in scientific knowledge, taking into account technical and economic considerations and bearing in mind the developmental needs of developing countries (UNEP Ozone Secretariat, 2007)".

A 2010 reassessment of the use of methyl bromide in New Zealand by the EPA concluded that: due to the ozone depleting nature of methyl bromide, and the indirect effects on public health and the environment, that all fumigators will be required to use recapture or destruction technology from 2020 onwards.

3.3.3 Health concerns

Apart from the indirect health concerns caused by the depletion of the ozone layer there are many direct health and safety concerns that result from exposure to methyl bromide. This section details the health concerns resulting from the inhalation of methyl bromide vapours - the most likely form of exposure resulting from tent fumigation operations. If methyl bromide is inhaled approximately half of the gas will pass through the lungs into the bloodstream (Agency for Toxic Substances and Disease Registry, 1992). The toxic effects resultant from inhalation are delayed, with a latent period varying between 0.5 to 48 hours depending on the intensity of exposure (Ministry for Primary Industries, n.d). The classification of risks pertaining to methyl bromide usage, under the Hazardous Substances and New Organism Act 1996 (HSNO), as determined in 2010 by the EPA is summarised in Table 2. The health impacts identified under the HSNO system are then further discussed below.

Table 2: HSNO classifications of methyl bromide risks

Hazardous property	HSNO classification	Description
Flammable gas	2.1.1B	Flammable gas - medium hazard
Acute toxicity (oral)	6.1C	Acutely toxic
Acute toxicity (inhalation)	6.1B	Acutely toxic - Fatal
Skin irritancy/corrosivity	8.2C	Corrosive to dermal tissue UN PGIII
Eye irritancy/corrosivity	8.3A	Corrosive to dermal tissue UN PGI
Mutagenicity	6.6B	Suspected human mutagen
Reproductive/ developmental toxicity	6.8B	Suspected human reproductive or developmental toxicants
Target organ systemic toxicity	6.9A	Toxic to human target organs or systems
Aquatic ecotoxicity	9.1A	Very ecotoxic in the aquatic environment
Soil ecotoxicity	9.2A	Very ecotoxic in the soilenvironment
Terrestrial vertebrate ecotoxicity	9.3B	Ecotoxic to terrestrial vertebrates
Terrestrial invertebreate ecotoxicity	9.4A	Very ecotoxic to terrestrial invertebrates

Inhalation of methyl bromide frequently leads to a spectrum of neurological effects in humans. At acute exposure of high concentrations, the affected person will nearly always experience injury to the central nervous system. Initial symptoms usually develop several hours after inhalation, with typical symptoms including: headaches, nausea, confusion, weakness, numbness and visual disturbances. If exposure is prolonged the neurological effects will have a quicker onset, and the person will potentially be subjected to: a loss of coordination, tremors, seizures, paralysis or even coma.

Inhalation also commonly results in significant damage to the affected persons lungs. Swelling of lung tissue is common at acute exposure and is often accompanied by focal haemorrhagic lesions. The swelling of lung tissue can result in a reduced amount of oxygen from reaching lung tissues, potentially leading to cyanosis, or even complete respiratory failure. At prolonged exposure, fluid may build up in the lungs and exacerbate the symptoms experienced from acute exposure.

Other organs sensitive to methyl bromide exposure include the kidneys, liver, skin and eyes. Effects resultant from exposure to the kidneys typically include either anuria or oliguria - which is the cessation of, or a reduction in, urine production. The liver may become swollen and tender in some cases, with congestion or focal haemorrhaging occurring. However, liver damage is typically not significant. At high concentrations of vapour, exposure to the skin may result in itchiness, redness and severe blistering - with symptoms generally appearing a few hours after exposure. Similarly, high concentrations of vapour can damage the eyes, leading to conjunctivitis, erythema, rashes, or even blisters.

There have not been any studies regarding the reproductive effects in humans following inhalation of methyl bromide. Research in male rats has shown delayed spermination, tubular degeneration and atrophy of the testicles. Despite this, the afflicted rats were found to have no significant difference in reproductive functions and impregnation rates. A study of rabbits that were exposed to 80ppm of methyl bromide during gestation resulted in a significant increase in developmental abnormalities of offspring. It is hypothesized that high levels (levels that would also cause significant neurological and pulmonary damage) of methyl bromide exposure may result in reproductive and developmental effects in humans.

Methyl bromide has also been shown to methylate DNA in both living and in isolated non-human cells without requiring metabolic activation - indicating that the compound has mutagenic potential. Due to the potential mutagenicity of methyl bromide it is possible that long-term exposure may lead to increases in tumour frequency, as such, the compound is a potential carcinogenic substance.

In serious cases, inhalation of methyl bromide can cause death. The cause of death is likely due to neurological injuries and/or pulmonary injury and associated circulatory failure. Death following exposure is not immediate and typically occurs within 1-2 days of exposure. Lethality has been reported in humans following exposure of concentrations between 1,600 ppm and 8,000 ppm for 4 to 6 hours of exposure, of for 2 hours exposure at 60,000 ppm. If death does not result from exposure, the neurological and pulmonary effects typically decrease in severity over a period of several weeks to several months. However, frequently, the neurological symptoms resulting from exposure will not completely subside (Agency for Toxic Substances and Disease Registry, 1992).

3.3.4 Usage

3.3.4.1 Restrictions

Under the Montreal Protocol methyl bromide has been recognised as an ozone-depleting substance and subsequently control mechanisms have been put in place to restrict its use. In 1992, the parties to the Montreal Protocol agreed to phase out the production and consumption of methyl bromide by 2005 for developed countries (including NZ), and by 2015 for developing countries. There are three categories of methyl bromide use that have been exempted from the phase out measures; the use of methyl bromide as a chemical feed stock (including work in labs); uses that parties to the Montreal Protocol deem 'critical'; and the use for quarantine and pre-shipment (QPS) purposes (UNEP Ozone Secretariat, 2007). Globally, approximately 95% of the methyl bromide used for non QPS activities has been phased out (Minister for the Environment, 2017)

Critical use exemptions can be given to countries where there is a lack of suitable alternatives to using methyl bromide so that the functioning of society is not disrupted. Applications for critical use exemptions can be made providing that it can be scientifically proven that there is no economically or technically feasible alternatives to the use of methyl bromide. Applications also require that research programmes are put in place to evaluate potential alternatives. (Department of the Environment, 2014). New Zealand previously had a critical use exemption to use methyl bromide as a soil fumigant for the strawberry and strawberry runner growing industry. However, this exemption expired on the 31st December 2007. There are currently no critical use exemptions in place in New Zealand (Envrionmental Risk Managment Authority, 2010).

Under the Montreal Protocol, quarantine and pre-shipment uses are defined as follows (UNEP Ozone Secretariat, 2007):

A) "'Quarantine applications', with respect to methyl bromide, are treatments to prevent the introduction, establishment and/or spread of quarantine pests (including diseases), or to ensure their official control, where:
   - i) Official control is that performed by, or authorized by, a national plant, animal or environmental protection or health authority;
   - ii) Quarantine pests are pests of potential importance to the areas endangered thereby and not yet present there, or present but not widely distributed and being officially controlled;

B) 'Pre-shipment applications' are those non-quarantine applications applied within 21 days prior to export to meet the official requirements of the importing country or existing official requirements of the exporting country. Official requirements are those which are performed by, or authorized by, a national plant, animal, environmental health or stored product authority."

3.3.4.2 Usage in New Zealand

All methyl bromide currently being used in New Zealand is exclusively for QPS purposes. An important part of the Montreal Protocol definitions is that they refer to official actions – meaning that, for any QPS applications, methyl bromide can only be used if authorised by the Ministry of Agriculture and Forestry Biosecurity New Zealand or other relevant government agencies (Envrionmental Risk Managment Authority, 2010).

The total consumption of methyl bromide for QPS purposes in New Zealand have tended to increase from the year 2000 to 2014 (Figure 2) - despite obligations of the Montreal Protocol to refrain from methyl bromide use (Envrionmental Risk Managment Authority, 2010; Minister for the Environment, 2017). In 2015 the national consumption of methyl bromide has been approximated at 525 tonnes, or 6.2% of the total worldwide consumption of 8,450 tonnes (STIMBR, 2017).

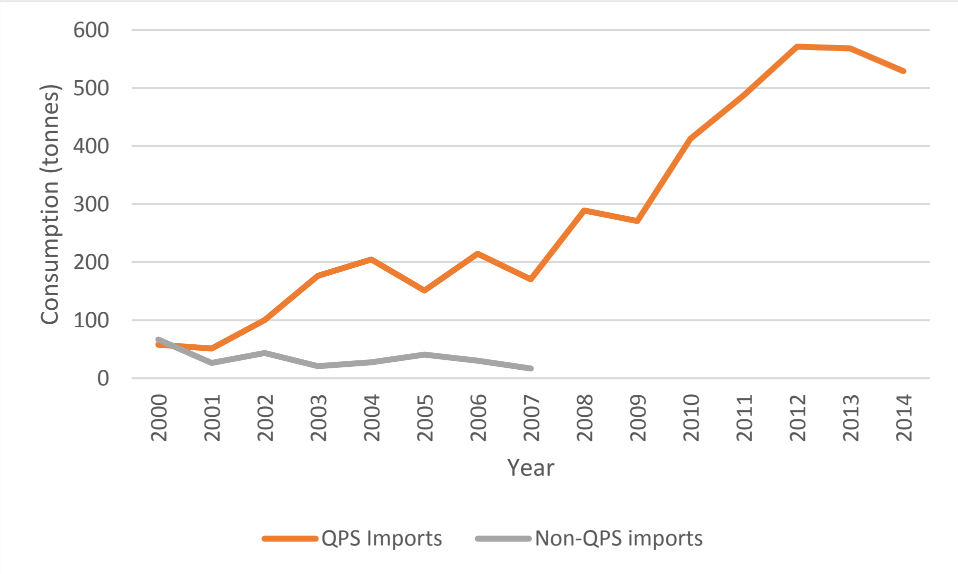

Figure 2: Nationwide methyl bromide consumption (Minister for the Environment, 2017)

The increase of methyl bromide usage in New Zealand is directly linked to an increase of log and log product exports (Envrionmental Risk Managment Authority, 2010). The total volume of log and wood chip exports increased from 6.9 million cubic metres in the year 2000 to 17.2 million cubic metres in 2014 (Figure 3). Other QPS uses of methyl bromide include the fumigation of: cut timber, imported goods in shipping containers, and commodities at transitional facilities and quarantine treatment centres.

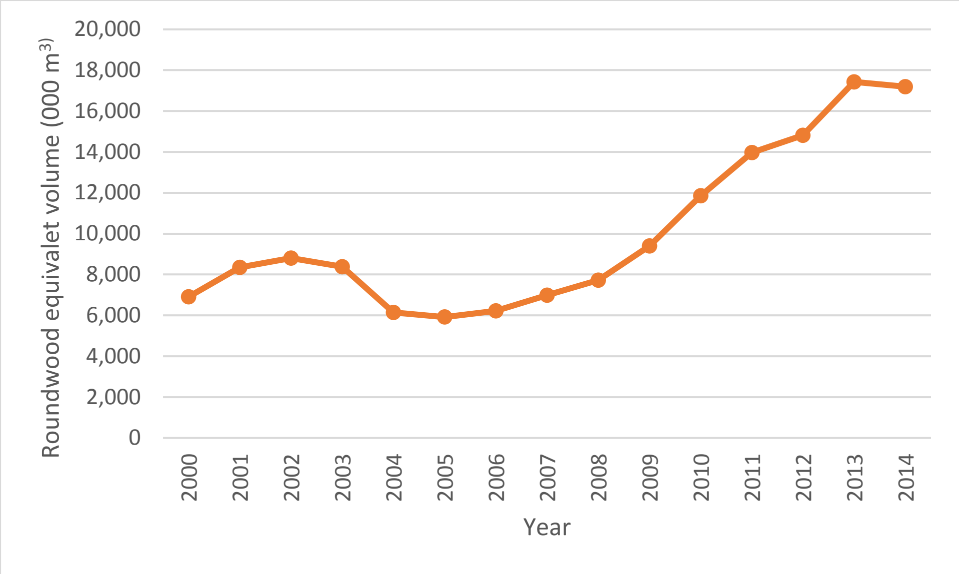

Figure 3: National log and wood chip export volumes (Ministry for Primary Industries, 2016)

Of the 13 million cubic metres of logs that were exported to China and India in 2015 approximately 3.7 million cubic metres required treatment with methyl bromide (Ministry for Primary Industries, 2016; STIMBR, 2017). Given the decision by ERMA that all methyl bromide must be recaptured or destroyed from 2020 onwards, should this not be possible, alternative treatment will be required for approximately 4 million cubic metres of log exports.

3.3.5 Fumigation process

Logs fumigated with methyl bromide on port are exclusively loaded onto the deck of shipping vessels. The reason for this is that logs in a ships hold can be fumigated at a lower cost by using either methyl bromide or phosphine during transit. Furthermore, tent fumigation is currently the only approved phytosanitary method that can be used at a scale appropriate to the volume of deck cargo currently being exported.

The process of tent fumigation is laid out in Figure 4. Firstly, log trucks arrive at the stevedoring checkpoint at Marsden Point where they are scaled and ticketed. The tickets provide information for each log, including: log supplier, logging contractor, forest harvested from, felling date, log length, and log volume. Once logs have been through checkpoint they are allocated to rows on the wharf. Providing that the row does not need to be relocated then fumigation can begin.

The first part of the fumigation process involves locking out the area so that unauthorized persons are unable to enter the area – for health and safety requirements. Following lock out, hoses are installed throughout in order to disperse the fumigant relatively evenly throughout the row. After hoses have been installed the row is then covered with a low permeability tarpaulin to minimise gas leakage out into the atmosphere. A ‘snake’ filled with either water or sand is then placed around the perimeter of the row to prevent leakage from underneath the tarpaulin. Once the tarpaulin is secured, methyl bromide is then released from a pressurised tank into the row through the hoses. The required duration and concentration of fumigation is defined by the importing countries phytosanitary requirements and is dependent on ambient temperature (Table 1). Once fumigation is completed the snake and tarpaulin is removed and the row is vented until the concentration of methyl bromide drops below 0.05 ppm (Envrionmental Risk Managment Authority, 2010). Once the row has been vented it can then be loaded onto the vessel.

An important part of the fumigation process is that the volume of logs fumigated needs to be greater than the allocated vessel volume. This is a requirement of exporters as the unit shipping rate will increase if the vessel is not fully loaded. Furthermore, if a sufficient volume is not available to fully load the vessel it will take additional time to fumigate additional logs and get them securely stowed on the ships deck, resulting in demurrage costs for the exporter (a cost for failing to discharge a vessel within the agreed timeframe). The economic importance of over-fumigation is that fumigated logs only have a short period in which they can be loaded onto a vessel, therefore, any excess cargo that has been fumigated but not loaded poses a cost to the exporter.

It is important to note that any logs fumigated with methyl bromide are required to be loaded onto vessels within 36 hours in summer during the burnt pine longhorn beetle, *Arhopalus ferus*, adult flight season; or within 72 hours in the remainder of the year. This requirement is in place to mitigate the risk of quarantine pests re-establishing themselves post treatment (Armstrong, Brash, & Waddell, 2014).

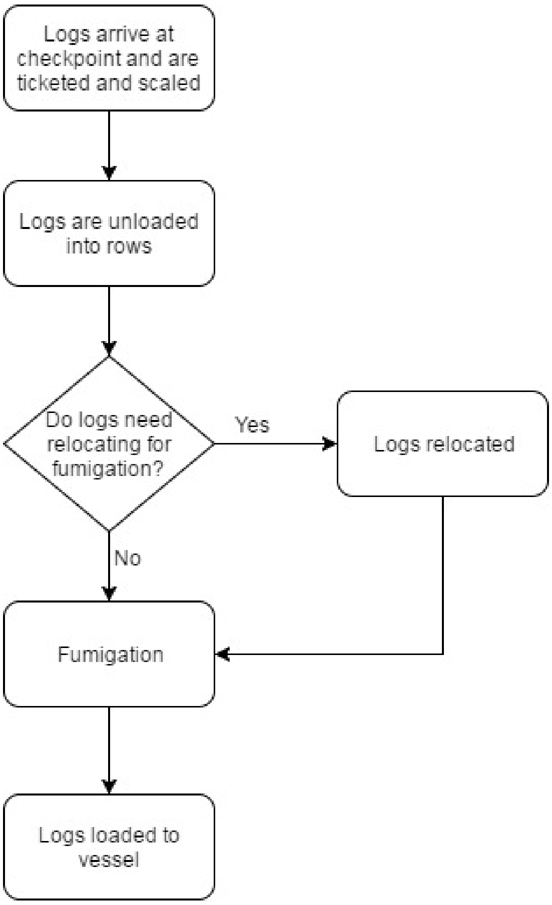

Figure 4: Tent fumigation process flowchart

3.3.6 Health and safety requirements

The 2010 EPA review of methyl bromide strengthened the previous controls in place and added new measures to further mitigate the health and safety risks involved with fumigation. The tolerable exposure limits (TELs) allowed for contact with methyl bromide were amended to include three different time periods: for chronic exposure, 24 hour and 1 hour of exposure. The chronic value is derived on the basis that a person exposed to this concentration for a lifetime should not suffer adverse effects. The revised TELs are as follows:

- TEL_{air} (chronic, annual average): 0.0013 ppm (0.005 mg/m^3)
- TEL_{air} (24 hour): 0.333 ppm (1.3 mg/m^3)
- TEL_{air} (1 hour): 1 ppm (3.9mg/m^3)

The EPA also set minimum buffer zones around fumigation areas that should result in the 1-hour TEL being achieved on the majority of occasions. The minimum buffer zone determined for tent fumigation operations was set at 50 metres. It is also required that signage is in place at every access point to the buffer zone. The signage must be: visible in darkness, in a position that it is readily seen by approaching persons, and it must state:

- That fumigation is being carried out; and
- That methyl bromide is being used; and
- That methyl bromide is toxic to humans; and
- The general hazards associated with methyl bromide; and
- The contact information for the person in charge of the site; and
- The date on which fumigation commenced.

In addition to the minimum buffer zones, the requirement to monitor air quality was imposed to ensure that practices are being managed in accordance with TEL values. Air quality monitoring is only required during venting and must continue until methyl bromide concentrations drop below 0.05 ppm (the effective limit for detection devices) for at least 3 minutes for operations using less than 7kg of methyl bromide, or for 15 minutes when more than 7kgs is used. Furthermore, standards were put in place for fumigators to produce and annual report detailing fumigation operations, and requiring fumigators to notify neighbours of operations.

3.4 Debarking

3.4.1 Operational requirements

The main operational requirement for debarking operations is the necessity to meet the phytosanitary requirements set by importing countries. For Chinese markets this requires individual logs to have no more than 5% bark by volume remaining, and that the bark volume remaining on entire consignments must be no greater than 2% (Ministry for Primary Industries, 2017).

There are several debarking systems than could be used to meet these phytosanitary requirements. However, as log quality is also an important driver for log exporting operations this excludes the use of some debarking systems; including: drum, chain flail, rosser head, and finger drum debarkers. Log quality is important for customers as there is an expectation to receive minimally damaged logs. This is because damage to the outer layer of the log can negatively impact the recovery of merchantable veneers or lumber; effectively reducing the value of the product the customer receives. To deliver a product with minimal damage, the best system for debarking softwood logs has been identified as a ring debarker, ideally a twin ring system (Armstrong, et al., 2014).

Ring debarkers work by using a conveyer belt to transport logs onto a series of feed rollers which centres logs as they are moved through a rotating ring of knives. As the ring rotates pressurised air is used to overcome the centrifugal force generated from rotation and pushes the knives against the log. The air pressure used can be adjusted to match the diameter and bark thickness of logs so that the knives are pushed against the cambium layer in order to effectively remove the bark. Twin ring systems are preferable to single ring systems for a couple of reasons. Firstly, having a second counter-rotating ring in the debarker will mean the knives will pass over knots and irregularities from two directions; likely resulting in an increased proportion of bark removal. Another advantage of a twin ring system is that if one ring needs maintenance it can be removed from the machine whilst leaving the other ring operating, effectively reducing down time (Nicholson Manufacturing Ltd, 2008)

A requirement of ring debarking operations is that only reasonably straight logs with minimal defects (such as fluting and nodal swelling) are suitable to be included in the production mix. If logs with poor geometry (due to defects such as nodal swelling, fluting, sweep, scars, and so on) are put through the debarker then it is unlikely that they will be able to meet the phytosanitary requirements in single pass through the plant. Another requirement is that the diameter of logs being debarked must be within the range in which the knives can adjust to. If logs are too small they will not come into contact with the knives and subsequently will not be debarked. If logs are too large they will not be able to fit into the machine and will likely cause mechanical damage.

3.4.2 Debarking process

Should a new debarking facility be built to debark export logs it would make sense to place the plant on, or near the port. The benefit of placing the debarker close to the port is that it will allow greater economies of scale and minimise transport costs - compared to if the plant was placed elsewhere (Auge & Clarke, 2015). The reason for this is that ports are at the end of local supply chains for log exports.

The debarking process is laid out in Figure 5. Similar to the fumigation process, logs will first arrive at checkpoint where they are scaled. Following scaling, logs will then be sent to the debarking facility. If logs are able to be hot-decked (immediately unloaded into infeed and debarked) then there are minimal logistical differences between debarking and fumigation operations. If hot-decking is unavailable there will be an additional step in the supply chain - unloading logs from trucks onto an intermediary storage yard, which will then need to be transported to the debarker infeed for processing. In either case, there will be additional handling and transport costs as debarked logs will need to be transported from the outfeed to storage rows using a mobile plant and/or trucks.

It is important to note that there is no time frame on how long debarked logs can sit on the port before they are shipped. As such, debarking plants can operate irrespective of whether any vessels are due to be loaded.

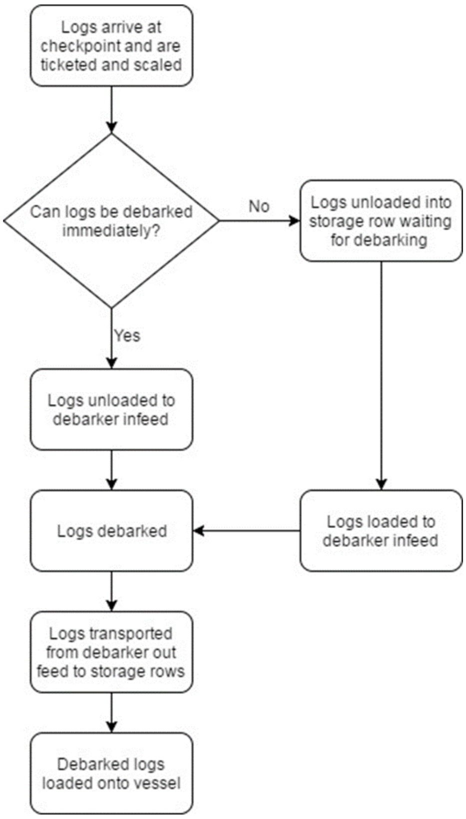

Figure 5: Debarking process flowchart

3.4.3 Factors influencing cost

There are multiple factors which will influence debarking cost, including: shipping load improvements, bark disposal, additional handling costs, machine specifications, production mix, throughput volume, and other factors.

As the quantity of logs able to be loaded onto vessels is limited by weight not volume this means any weight saved by removing bark will result in a greater volume of logs able to be loaded onto a vessel - effectively reducing the unit shipping rate. The reduction in unit shipping rate will depend on the weight of bark remaining on logs when they reach the debarking plant. The weight of this bark will depend on how much bark there is on standing trees, the proportion of bark that is removed during harvesting and transport, and the moisture content of the bark.

Significant volumes of bark produced will be produced from debarking operations that will need to be disposed of. Currently bark is removed from ports at no cost and is primarily used for landscaping, fertilizer, horticulture, and hog fuel. However, if the entire volume of logs currently being fumigated were to be debarked it could saturate bark markets and may result in a cost for bark removal and disposal. Conversely, if markets were developed that require bark for its chemical properties it is possible that a premium could be paid for bark - resulting in an additional revenue stream.

There will be additional handling costs for transporting logs that have been debarked for two reasons. Firstly, as mentioned above, logs will need to be stored in an intermediary yard and then transported to storage rows on the wharf using mobile plants (Armstrong, et al., 2014). Because this requires more handling than methyl bromide fumigation, an additional cost for the extra handling and transportation will be imposed. The additional handling costs will be less if hot-decking is available – however, it is unlikely that many logs will be able to be hot-decked as it would result in a backlog of log trucks waiting for logs to be processed. Secondly, removing bark from logs results in a reduced coefficient of friction. The implications of a reduced coefficient of friction is that debarked logs are more likely to move than bark-on logs when subjected to forces. This will make it harder for loader operators to control the logs in the machines grab, as well as increasing the likelihood for logs to slide on the back of moving trucks (Murphy, 2016).

The type of debarking machine used will directly influence the capital, maintenance, power, land, and staffing costs for running the plant. Furthermore, debarker capacity will be a function of the line speed of the plant, plant efficiency, and how many shifts are being run each year. Debarker capacity will also be heavily influenced by the production mix. The production mix will influence unit costs as the line speed of the plant should remain constant irrespective of log diameter, assuming that logs have good geometry. Because of this, putting larger diameter logs through the plant will result in a greater volume throughput in a given time period and subsequently will result in lower unit costs, when compared to smaller diameter logs.

Total volume throughput will also influence debarking rate. By increasing throughput volume a reduction in unit cost will be expected due to increased scales of economy, as capital and staffing costs are fixed. Other factors influenced by throughput volume will include the amount of power required to operate the plant and the amount of intermediary storage required – both of which are expected to increase as throughput volume increases.

Other factors that will influence debarking rate include whether the plant has anti-sapstain and/or log scanning and bar-coding capabilities. In the case of anti-sapstain capabilities this could also introduce some environmental concerns due to the use of chemicals and the need to recycle water. If either of these technologies were to be incorporated into the plant there would be an increase in capital cost. However, the increase in capital costs could potentially be offset by the additional services provided (Armstrong, et al., 2014). For the purposes of this dissertation none of these additional factors have been factored into the cost of debarking as they are superfluous to meeting phytosanitary requirements.

3.5 Alternative treatments

Ethanedinitrile (EDN) has been identified as a potential direct substitute for methyl bromide fumigation. However, the efficacy and environmental impacts of EDN needs further evaluation. Furthermore, it will take time for EDN to gain recognition by importing countries. As such, EDN will not be able to be used come the 2020 EPA deadline (Armstrong, Brash, & Waddell, 2014).

Joule heating is a technology being developed that uses electricity to heat logs in order to kill unwanted organisms with heat. The proof of concept for joule heating has been completed for treatment of single logs and work is being done to build a pilot test facility that treats multiple logs on a large scale simultaneously (Gifford Consulting, 2015). Again, this technology will not be viable on a large scale by the EPA deadline.

4. Methods

4.1Methyl bromide fumigation costs

Historic shipping manifests and fumigation invoices were used to calculate the true cost of methyl bromide fumigation. Pacific Forest Products (PFP) shipping manifests from 2015 and 2016 were looked up to find the volume of deck cargo loaded onto each shipping vessel. Historic invoices from Genera (the fumigation service provider) detailing the volume fumigated and the unit fumigation rate were looked up for each of the vessels in the same timeframe. The unit fumigation rate for each vessel was then divided by the volume loaded onto deck to calculate the proportion of over-fumigation. The unit fumigation rate was then multiplied by the proportion of over-fumigation to calculate the true cost of fumigation. The true cost was then rebased to June 2017 values using producer price index data from Infoshare. Finally, a volume weighted average of the real true fumigation cost was calculated to find the actual average unit fumigation cost.

4.2 Log statistics

PFP's 2016 cart in data provides information for every truckload of logs delivered to Marsden Point, including: grade, sale length, weight, JAS volume, average SED, and the number of pieces delivered. This information was used to provide details regarding the average piece length, volume, and volume per metre for the debarking production mix, for each log grade, and for each log grade by length. To simplify the analysis log grades were amalgamated into four lengths by taking a volume weighted average. The lengths used in analysis are 3 metres (combining 2.9 and 3 metre lengths), 3.8 metres (3.6, 3.8 & 3.9 metre lengths), 5.1 metres (4.5, 4.8, 5.1, 5.4 & 5.5 metre lengths), and 5.8 metres (5.8, 5.9 & 7.7 metre lengths).

4.3 Resource availability

Information from the 2014 Northland Wood Availability Forecast (WAF) was used to estimate future wood supply volumes in the region. Scenario number 2 from the WAF was used to project available wood volume, which assumes that: large-scale forest owners will harvest at stated intentions until 2023 with volumes non-declining after this period; and for the total wood supply, a non-declining yield constraint is applied in perpetuity with a target rotation age of 28 years from 2020 onwards (Indufor Asia Pacific Limited, 2015).

WAF information was then used in conjunction with MPI data on the volume of roundwood removals and local processing to estimate available wood supply. The average volume of roundwood that was processed locally from 2012 to 2016 has been assumed to remain constant in future years and was then subtracted from the WAF to project future export volumes.

The forecasted available export volume was then converted into JAS m^3 using PFP JAS m^3 to m^3 conversion rates (Table 3). An assumption has been made that the proportion of grades making up the forecasted available volume will be same as the proportion carted in by PFP in 2016, and that 70% of the available volume will be exported as deck cargo.

Table 3: PFP JAS m^3 to m^3 scale conversion factors

	JAS m3 to m3 scale conversion						
Log grade	Pruned	A-Oversized	Small-Pruned	A-Grade	KI	K-Grade	Pulp
Conversion rate	1.03	1.03	1.03	1.03	1.03	0.96	0.91
% Cartin Volume	9.6%	3.7%	7.3%	25.0%	13.0%	25.6%	15.7%

Cart in information was also used to project the volume that will requiring debarking by log grade, log grade by length, and for different production mixes. Two different production mixes were evaluated to determine the total volume requiring debarking. The first production mix included all log grades with suitable geometry for debarking: Pruned, Small-Pruned, A-Grade, A-Oversize, and K-Grade. The second production mix excluded K-Grade logs due to having small diameters and subsequently low volumes.

4.4 Shipping load improvements

To calculate the weight removed from debarking and the associated saving in shipping rates a standing bark volume of 13.4%/m^3 has been used. It has been assumed that the bark will still be wet by the time logs reach the port and will have a green density of 641 kg/m^3 (Miles & Smith, 2009). To determine the proportion of bark remaining on logs by the time they reach the port it has been assumed that 65% of bark volume will be lost during harvesting, handling, and transportation (Murphy, 2016). Using these figures, the weight of bark on each cubic metre of wood can be approximated. The percentage of weight removed from debarking was then calculated by dividing the weight of bark per cubic meter by the weight of wood, which has been assumed to be 1000kg/m^3 at the time of shipping. The percentage weight removal was then used in conjunction with PFP's average freight cost from 2012 to 2017, \$26/JAS m^3, to determine how many more logs could be loaded on deck and the associated reduction in unit shipping rate.

4.5 Bark removal

In order to calculate the volume of bark removed, the JAS m^3 volume being debarked first needs to be converted back into m^3 using the appropriate conversion factors (Table 3) for each production mix. After conversion from JAS m^3 into m^3 the cost of bark disposal has been evaluated using three different scenarios. The first scenario reflects the current bark disposal operations at the port; where bark is removed at no cost for landscaping and fertilizer purposes by the company Daltons. The second scenario assumes that the market for bark will become saturated due to an increased supply and subsequently a cost of $20/$m^3$ will be imposed for removal and disposal. The final scenario assumes that a premium of $20/$m^3$ will be paid for bark due to an increase in demand for bark in landscaping, fertilizing, horticultural, and hog fuel markets; and/or markets will be developed that use bark as a chemical feedstock.

4.6 Additional handling costs

Based on the additional costs currently being paid by PFP for handling and transporting logs from the current debarker at Marsden Point to storage rows on the wharf, a rate of $1.80/JAS m^3 has been used to estimate the extra costs for debarking relative to methyl bromide fumigation operations.

4.7 Plant capacity

The specifications for the Nicholson A5C 27" debarker used in this dissertation, as supplied by Wilson Processing Solutions (WPS), are shown in (Table 4). The model used to calculate plant capacity (Equation 1) was also supplied by WPS. To account for downtime resulting from breakdowns and maintenance, and the fact that there will be gaps between each log passing through the debarker, an operational efficiency of 60% has been assumed. It is expected that the plant will run for 270 days a year on 12-hour shifts.

Table 4: Nicholson A5C debarker costs and specifications

Nicholson A5C 27"	
Capital cost	$ 4,737,577
Mechanical cost / year	$ 262,846
Minimum line speed	60 metres / minute
Maximum line speed	90 metres / minute
Maximum log diameter	680 millimetres
Minimum log diameter	89 millimetres
Minimum log length	2.24 metres

Equation 1: Debarking plant capacity

$$Capacity = line\ speed\ /\ average\ piecelength * average\ piece\ size * shift\ length * number\ shifts * 60 * operational\ efficiency$$

The average piece size and length from cart in data was used to determine the overall capacity for each production mix. The percentage volume difference relative to overall plant capacity was calculated for each log grade and length in order to determine the influence of putting different log lengths and grades through the debarker. This was achieved by using the average piece size and length for each log grade, and grade by length, as inputs into the capacity equation.

4.8 Costing model

A costing model was built to estimate the annual costs for running a Nicholson A5C 27” debarking plant. The capital and annual maintenance costs used in this model are equal to $4.74 million and $263,000/year, respectively (Table 4).

The cost of capital for the project has been assumed at 8%/year and it is expected that 1,800m^2 of land will be required to house the plant and to act as an intermediary storage yard. It has been assumed that the land will be leased at a rate of $20,000/ha per year. Assuming the plant will run 270 days a year on 12-hour shifts, the expected staffing costs have been set at $150,000 / year.

The amount of power required to run the plant each hour will be a function of throughput volume (Equation 2), as supplied by WPS. The average real cost of industrial electricity from 2012 to 2017, $112/Mwh (megawatt hour), has been used to calculate the price of powering the debarking facility (Ministry of Business, Innovation & Employment, 2017).

Shipping load improvements will reduce the annual costs for a debarking operation and will be a function of throughput volume and the percentage bark remaining on logs at the wharf gate. The volume being debarked will also influence how much bark is produced and will need to be disposed of. The base case model assumes that there will be a $1.80/JAS m^3 cost for the additional handling and transport required (compared to the fumigation process), and that there will be no cost for bark disposal; however, the model will also be run with a cost and a premium of $20/m^3 for disposal.

Equation 2: Debarking plant power consumption

$$Power\ consumption\ (Mwh) = 3.64583\ x\ 10^{-7}\ x\ \text{Volume throughput}$$

4.9 Debarking rate

To calculate the average debarking rate the expected annual cost of the debarking operation was divided by the throughput volume for each production mix. The debarking rate by log grade, and log grade by length, was calculated by multiplying the percentage differences in plant capacity, relative to each production mix, by the overall debarking rate.

5. Results

5.1 Methyl bromide fumigation cost

Each vessel was found to have, on average, an additional 1,704 JAS m^3, or 121% of the required vessel volume, which had been fumigated but not loaded onto deck (Figure 6). The volume weighted average unit fumigation rate for all vessels, before accounting for over-fumigation, was found to be \$3.98/JAS m^3. When the percentage of over-fumigation was accounted for, the true cost of fumigation was calculated at \$4.99/JAS m^3. After adjusting for inflation, the real cost of methyl bromide fumigation was found to be \$5.25/JAS m^3.

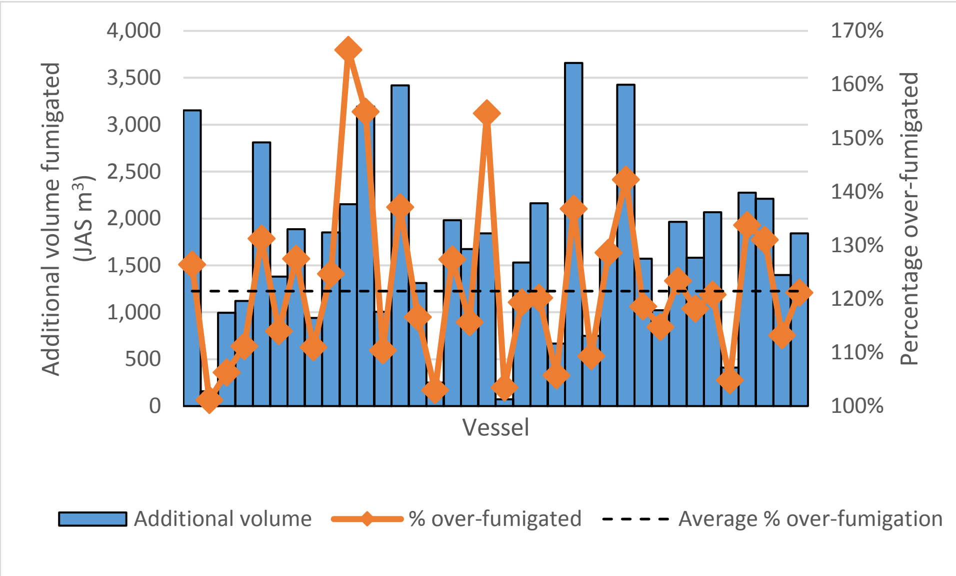

Figure 6: Volume fumigated but not loaded onto vessels

5.2 Log statistics

Of all the suitable log grades carted into Marsden Point in 2016 it was found that K-Grade accounted for the greatest proportion of volume (25.6%), followed by A-Grade (25.0%), Pruned (9.6%), Small-Pruned (7.3%) and A-Oversize (3.7%). It was also found that an increase in log length did not necessarily result in an increase in average volume per metre (Table 5).

When all suitable log grades for debarking were included in the production mix, the average log length, volume, and volume per metre was calculated at 4.61metres, 0.45 JAS m^3, and 0.097 JAS m^3/metre respectively. Given this production mix it was found that 71.3% of the volume of logs being carted into Marsden Point would be suitable for debarking.

When K-Grade was excluded from the production mix the average piece size per metre increased 151% to 0.146 JAS m^3/metre. There was also a small increase in average log length of 0.02 metres to 4.63 metres. If K-Grade were to be excluded from debarking operations then it would only be possible to debark 45.6% of the volume delivered to Marsden Point.

Table 5: Average JAS m^3 volume and percentage volume cart in by log grade and length

	Log Grade	Length (m)	Average volume (JAS m3)	Avg volume (JAS m3 / metre)	% of total cartin volume
Log grade by length	A-Grade	3.00	0.42	0.140	0.1%
	A-Grade	3.80	0.49	0.129	11.8%
	A-Grade	5.10	0.66	0.129	0.3%
	A-Grade	5.80	0.78	0.135	12.7%
	A-Oversize	3.80	0.88	0.233	3.7%
	K-Grade	3.80	0.23	0.062	14.5%
	K-Grade	5.10	0.34	0.067	3.1%
	K-Grade	5.80	0.37	0.064	8.0%
	Pruned	3.80	0.84	0.220	4.2%
	Pruned	5.20	1.12	0.215	4.9%
	Pruned	5.80	1.30	0.224	0.5%
	Small-Pruned	3.80	0.52	0.138	3.8%
	Small-Pruned	5.10	0.68	0.134	3.5%
Log grade	A-Grade	4.84	0.64	0.133	25.0%
	A-Oversize	3.80	0.88	0.233	3.7%
	K-Grade	4.58	0.29	0.063	25.6%
	Pruned	4.57	1.00	0.220	9.6%
	Small-Pruned	4.43	0.60	0.136	7.3%
	All Log Grades	4.61	0.45	0.097	71.3%
	Excluding K-Grade	4.63	0.68	0.146	45.6%

5.3 Resource availability

Based on the assumption that the average volume of Roundwood processed from 2012 to 2016, 1,474,000m^3/year, will remain constant in coming years it has been calculated that up to 1,372,000m^3 of logs could be exported from 2020 onwards (Figure 7). After converting from m^3 to JAS m^3 this results in a potential export volume of 1,382,772 JAS m^3. Given the assumption that 70% of this volume will be loaded on vessels as deck cargo this means that up to 967,940 JAS m^3 (960,400m^3) of logs will require alternative phytosanitary treatments should the use of methyl bromide cease.

As the production mix including all suitable log grades accounts for 71.3% of the total cart in volume, this means that debarking could be used as a phytosanitary treatment method for the 967,940 JAS m^3 (960,400m^3) of logs forecasted to be exported as deck cargo. When K-Grade is excluded from the production mix 65%, 630,544 JAS m^3 (625,632m^3), of the forecasted deck cargo volume would be able to be debarked; leaving 337,396 JAS m^3 (334,768m^3) that will require alternative phytosanitary treatment.

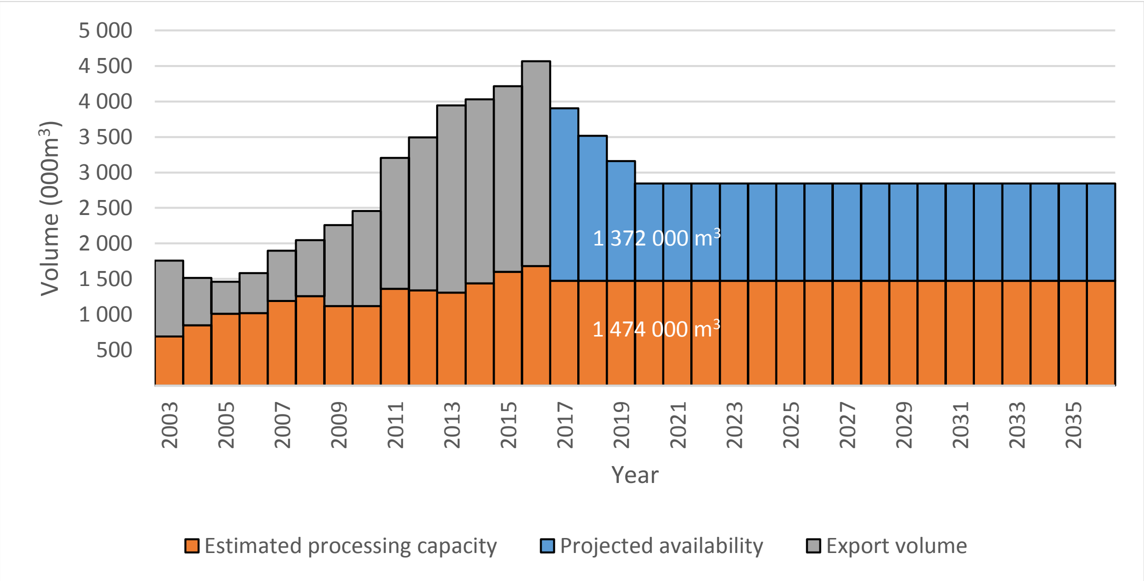

Figure 7: Projected wood availability in Northland

5.4 Shipping load improvements

Given the assumption that standing trees have 13.4% bark by volume and that 65% of this bark will be removed by the time logs reach the wharf gate, there will be, on average, 4.7% bark by volume remaining on logs when they reach the port. Assuming the weight of wet bark is equal to 641kg/m^3 this means each cubic metre of delivered wood will have approximately 30.1kg of bark remaining on it. Assuming that green radiata pine wood weighs 1000kg/m^3 when loaded onto vessels, this means that a 3% weight saving from removing bark can be expected. As deck cargo accounts for one third of a vessels volume this means that debarking will result in a 1% weight saving; which corresponds to a 1% increase in the total volume able to be shipped. Given that the PFP's average freight cost from 2012 to 2017 was $26/JAS m^3, a saving of $0.26/JAS m^3 can be expected from debarking.

5.5 Bark disposal volumes

A significant quantity of bark will be produced from debarking operations if 30.1kgs will be produced for every cubic meter of logs processed. If all suitable log grades (960,400m^3) were to be debarked this would result in 28,872,409kgs, or 45,043m^3, of bark that will need to be disposed of. When K-Grade logs are excluded from the production mix (625,600m^3) this results in 18,808,312kgs, or 29,342m^3, of bark being removed from logs.

5.6 Plant capacity

For the production mix including all suitable log grades for debarking, the maximum throughput capacity for a Nicholoson A5C 27" debarker was found to be 977,000 JAS m^3 per year. When K-Grade was excluded from the production mix the annual capacity increased 151% to 1,477,000 JAS m^3 per year. Results indicate that the average volume per metre is a more significant driver of annual throughput capacity compared to log length (Table 6).

Table 6: Expected debarking plant capacity by log grade and length

	Log Grade	Length (m)	Avg volume (JAS m3 / metre)	Maximum Capacity (JAS m3 / year)	Percentage capacity difference	
					All Log Grades	Excluding K-Grade
Log grade by length	A-Grade	3.00	0.14	1,414,335	145%	96%
	A-Grade	3.80	0.13	1,304,977	134%	88%
	A-Grade	5.10	0.13	1,305,336	134%	88%
	A-Grade	5.80	0.13	1,362,129	139%	92%
	A-Oversize	3.80	0.23	2,353,309	241%	159%
	K-Grade	3.80	0.06	623,871	64%	-
	K-Grade	5.10	0.07	678,094	69%	-
	K-Grade	5.80	0.06	650,315	67%	-
	Pruned	3.80	0.22	2,225,404	228%	151%
	Pruned	5.20	0.21	2,214,422	227%	150%
	Pruned	5.80	0.22	2,265,916	232%	153%
	Small-Pruned	3.80	0.14	1,392,648	143%	94%
	Small-Pruned	5.10	0.13	1,355,355	139%	92%
Log grade	K-Grade	4.58	0.13	638,727	65%	-
	A-Grade	4.84	0.23	1,334,509	137%	90%
	Small-Pruned	4.43	0.06	1,374,605	141%	93%
	Pruned	4.57	0.22	2,221,861	228%	150%
	A-Oversize	3.80	0.14	2,353,309	241%	159%

5.7 Debarking rate for all log grades

When all suitable log grades are included in the production mix and 967,940 JAS m^3 are debarked, the average cost of debarking for the base case model is expected to be \$2.52/JAS m^3 (Table 7). The primary factor influencing the unit debarking rate appears to be handling and transport costs, which accounts for 71% of the total debarking rate – at this scale.

When debarking rate is further broken down into log grade and length (Figure 8) it can be seen that log length is a relatively unimportant factor in influencing overall costs as there is no consistency between an increase in length and lower debarking rates.

When costs are shown by log grade (Figure 9) it can be seen there are three distinct levels in costs; with the volume weighted average debarking rate of Pruned and A-Oversized logs calculated at \$1.09/JAS m^3, A-Grade and Small-Pruned 168% higher at \$1.84/JAS m^3, and K-Grade costing 353% more at \$3.86/JAS m^3. It can also be seen that a higher average volume per metre corresponds to a lower debarking rate.

Table 7: Base case debarking costing model for production mix including all suitable log grades

Costing factors	Rate						Annual costs	% of total cost
Capital cost	$	4,737,577	@	8%	Capital cost	$	379,006.16	16%
Maintentance	$	262,846	Maintenace / Year			$	262,846.40	11%
Power	$	112	/ MWh @ 3120 hours / year @	0.35	MWh / Hour	$	123,315.59	5%
Land lease	$	20,000	/ ha @	0.18	ha	$	36,000.00	1%
Handling costs	$	1.80	$/JAS m3 @	967,940	JAS m3 / year	$	1,742,292.46	71%
Staff	$	150,000	Salaries / year			$	150,000.00	6%
Bark disposal	$	-	$ / m3 @	45,396	m3 / year	$	-	0%
Shipping load improvements	-$	0.26	$/JAS m3	967,940	JAS m3 / year	-$	249,670.20	-10%
					Total cost	$	2,443,790.41	
					Cost / JAS m3	$	2.52	

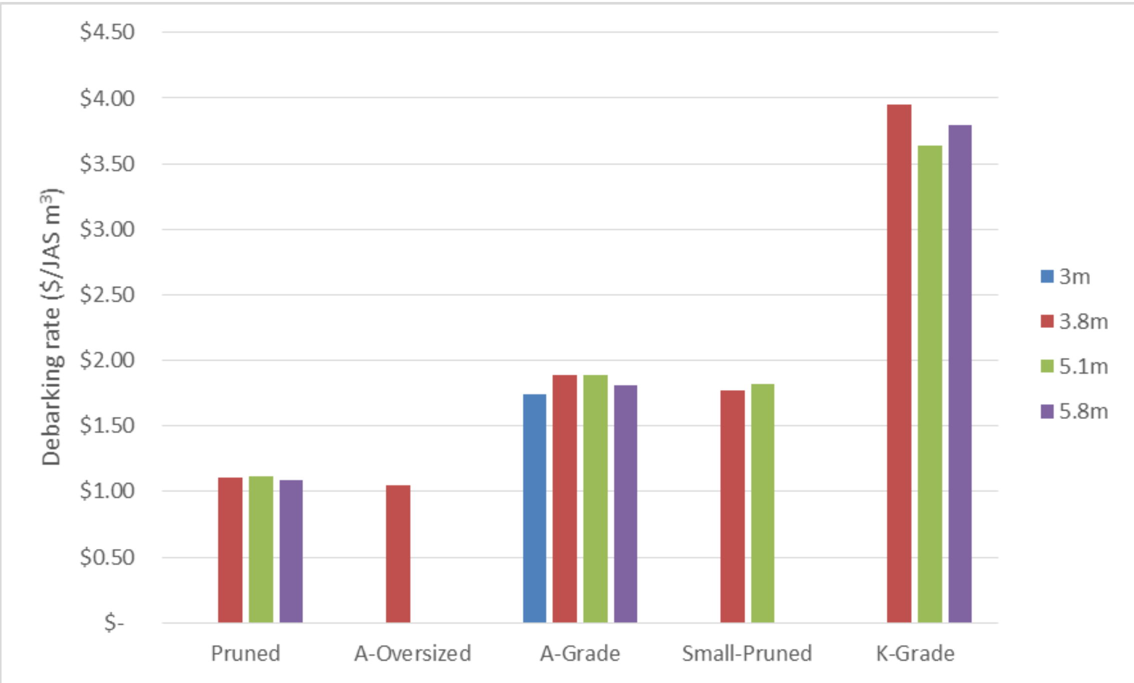

Figure 8: Debarking rate by log grade and length for all suitable log grades

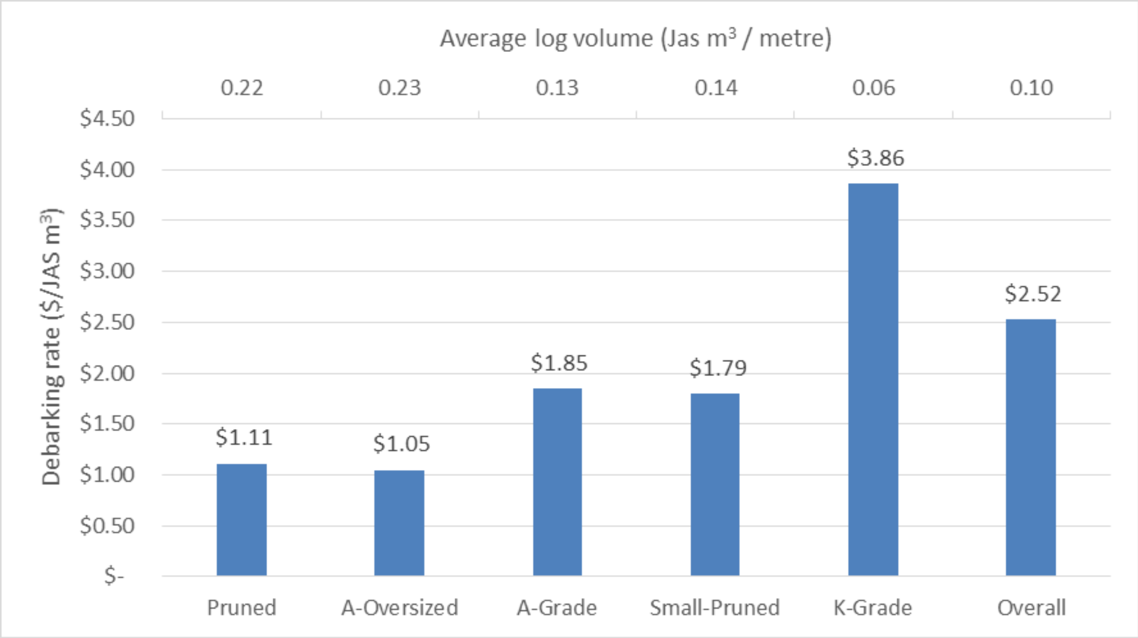

Figure 9: Debarking rate by log grade for all suitable log grades

5.8 Debarking rate when excluding K-Grade

When K-Grade is excluded from the production mix, 630,544 JAS m^3 of logs can be debarked each year, at an average debarking cost of $2.98/JAS m3 (Table 8), 18% more expensive than the production mix including all log grades. Similarly, handling and transport costs are the primary factor influencing debarking rate, accounting for 60% of the costs of the average debarking rate. When broken down by log grade (Figure 10) the weighted average cost of Pruned and A-Oversize log grades was found to be $1.95 / JAS m^3 and the cost of A-Grade and Small-Pruned logs was 168% higher at $3.28 / JAS m^3.

Table 8: Base case debarking costing model for production mix excluding K-Grade logs

Costing factors	Rate						Annual costs	% of total cost
Capital cost	$	4,737,577	@	8%	Capital cost	$	379,006.16	20%
Maintentance	$	262,846	Maintenance / Year			$	262,846.40	14%
Power	$	112	/ MWh @ 3120 hours / year @	0.23	MWh / Hour	$	80,331.30	4%
Land lease	$	20,000	/ ha @	0.18	ha	$	36,000.00	2%
Handling costs	$	1.80	$/JAS m3 @	630,544	JAS m3 / year	$	1,134,979.09	60%
Staff	$	150,000	Salaries / year			$	150,000.00	8%
Bark disposal	$	-	$ / m3 @	29,573	m3 / year	$	-	0%
Shipping load improvements	-$	0.26	$/JAS m3	630,544	JAS m3 / year	-$	162,642.30	-9%
					Total cost	$	1,880,520.64	
					Cost / JAS m3	$	2.98	

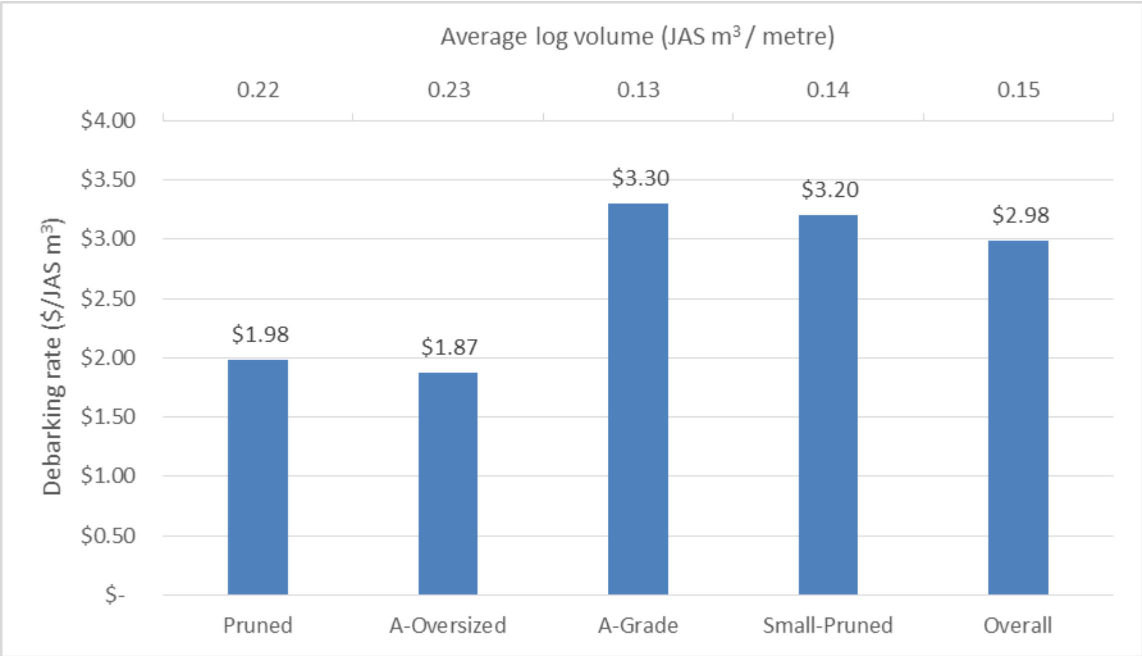

Figure 10: Debarking rate by log grade – excluding K-Grade

5.9 Sensitivity analysis

To determine the most critical factors influencing debarking rate, sensitivity analysis has been performed on the base case model with all log grades included in the production mix (Table 7).

The cost of debarking is heavily influenced by throughput volume, with the minimum cost of $2.52/JAS m^3 expected when throughput volume is at the maximum capacity of 976,539 JAS per year (Figure 11). If the available wood volume for exporting were to drop by 50% the average unit debarking would be expected to increase to $3.54/JAS m^3. Available wood volume would have to drop by 74%, to 250,000 JAS m^3, for the average debarking cost to be equal to the true cost of methyl bromide fumigation - $5.25/JAS m^3.

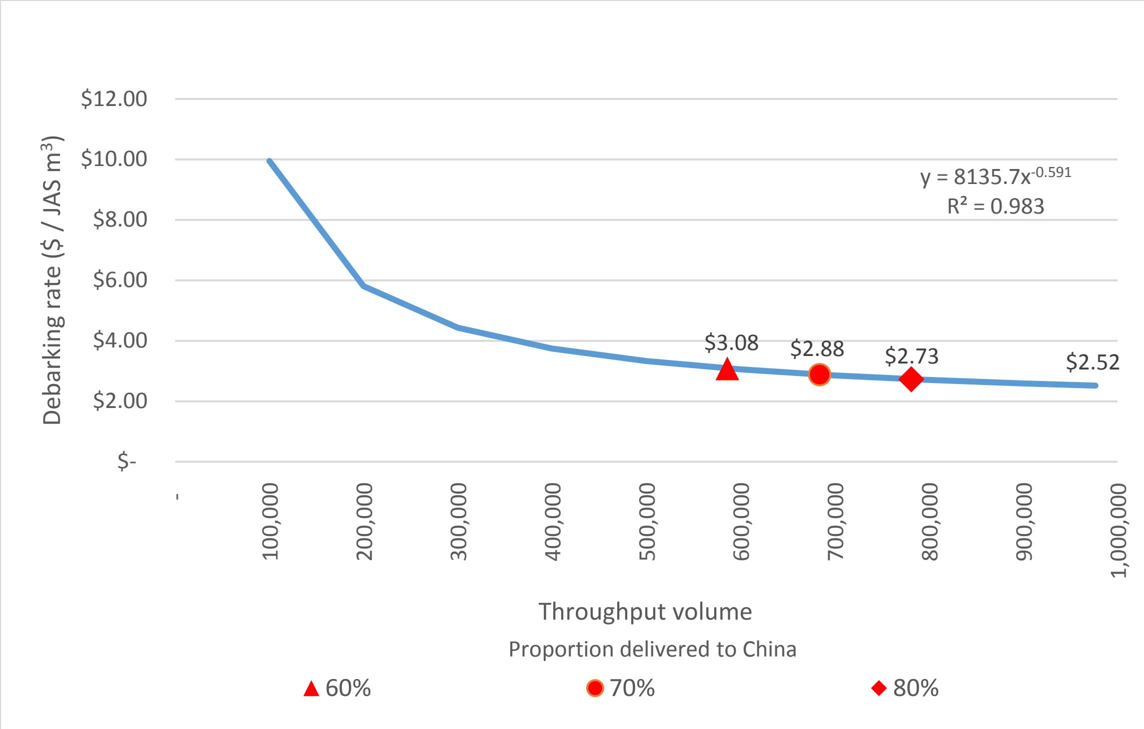

Figure 101: Base case model, for all suitable log grades, sensitivity to annual throughput volume

As China is the only log export market that currently approves debarking as a phytosanitary treatment it would be logical to only debark the volume of logs destined to Chinese Markets in order to minimise costs. Assuming that log exports out of Marsden Point are equal to the nationwide proportion of logs destined to China, approximately 70% of the projected available wood volume would require debarking. Should 70% of the logs exported from Marsden Point be debarked an average debarking rate of \$2.88/JAS m^3 would be expected. If the market share of log exports to China increased to 80% this would result in an average debarking rate of \$2.73/JAS m^3. Conversely, if Chinese market share dropped to 60%, the expected average debarking rate would be \$3.08 JAS/m^3.

Debarking rate is also very sensitive to any costs or revenue imposed on bark disposal. If a bark disposal rate of \$20/m^3 was imposed the average debarking rate would expect to increase by 37% up to \$3.46/JAS m^3 (Figure 12). The sensitivity of debarking rates to disposal rate also increases with the proportion of bark remaining on delivered logs, due to a greater volume of bark being produced. The discrepancy between debarking rates at no cost for bark disposal is due to the relationship with bark volumes and shipping load improvements; where a larger volume of bark remaining equates to more weight being removed and subsequently a larger saving in freight rates (Table 9).

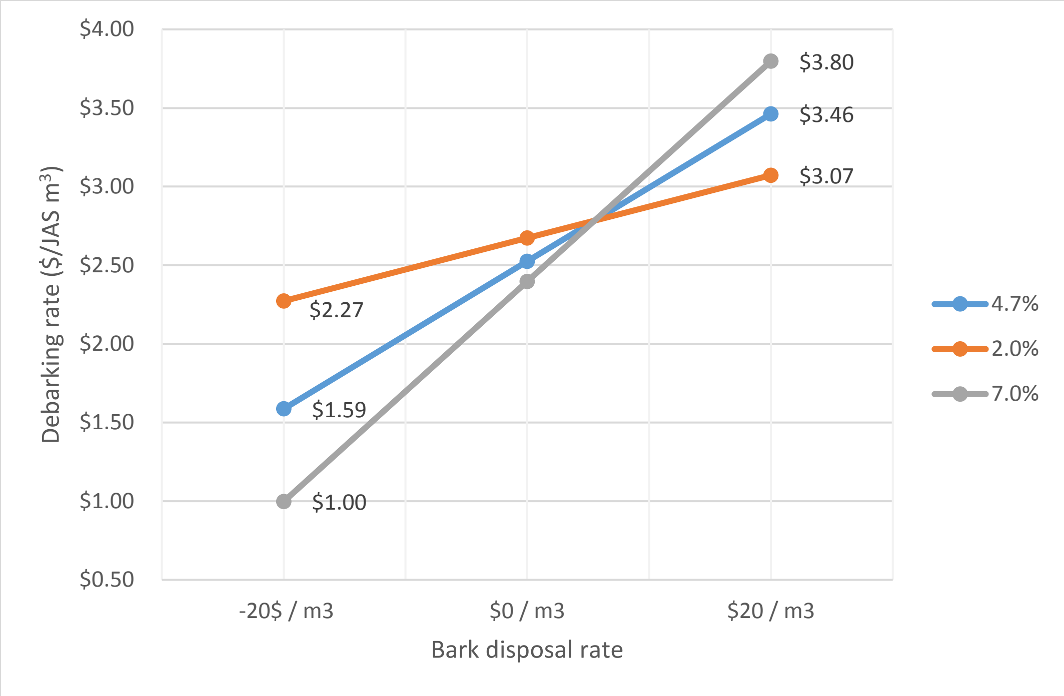

Figure 112: Debarking rate by bark disposal rate and remaining bark percentage

Table 9: Shipping load improvements as a function of percentage bark volume remaining

Bark volume remaining	Shipping load improvements
2.0%	-$ 0.11
4.7%	-$ 0.26
7.0%	-$ 0.38

Out of the other factors built into the costing model, handling and transport costs have by far the greatest influence on unit debarking rate (Table 10). Capital cost has the next greatest influence on debarking rate, followed by shipping load improvements and maintenance costs which have a similar impact on debarking rate. Staffing and power costs appear to have minor influences on debarking rate, and land lease appears to be almost negligible.

Table 10: Influence of costing factors on debarking rate

Costing factor	Difference from base case			Δ Debarking rate
	-10%	0%	+ 10%	
Handling costs	$ 2.34	$ 2.52	$ 2.70	$ 0.18
Capital cost	$ 2.49	$ 2.52	$ 2.56	$ 0.04
Maintentance	$ 2.50	$ 2.52	$ 2.55	$ 0.03
Shipping load improvements	$ 2.55	$ 2.52	$ 2.50	-$ 0.03
Staff	$ 2.51	$ 2.52	$ 2.54	$ 0.02
Power	$ 2.51	$ 2.52	$ 2.54	$ 0.01
Land lease	$ 2.52	$ 2.52	$ 2.53	$ 0.00

6. Discussion

Despite the unit debarking rate for K-Grade logs being 210% higher than A-Grade and Small-Pruned logs, and 353% higher than Pruned and A-Oversize logs, it was found to be more economical to include K-Grade logs in the debarking production mix for a Nicholoson A5C 27" debarker at Marsden Point. The reason for this is that greater scales of economies was achieved when K-Grade logs, which account for 26% of the total volume delivered to Marsden Point, were included in the production mix. An implication of this is that large diameter (and subsequently large volume) log grades are preferable to include in the production mix as they are cheaper to debark. However, if greater scales of economy can be achieved by including small diameter log grades in the production mix it may make debarking operations more economical, as is the case for Marsden Point.

Furthermore, when K-Grade was included in the production mix the annual debarking plant throughput capacity (976,538 JAS m^3) was 66% of the capacity when K-Grade was excluded (1,476,624 JAS m^3). Similarly, this implies that if there is a sufficient volume of large log grades available in the wood supply region, then preference should be placed to include them in the production mix in order to increase plant capacity. Having a greater throughput capacity will result in lower debarking rates, providing that sufficient volume is available to run the plant efficiently.

It was also found that log length was an unimportant factor for influencing debarking rates. There are a couple of reasons that could explain this. Firstly, logs are automatically fed from the debarker infeed through the plant. As the infeed process is automated the gap distance between logs passing through the plant is likely to be minimised. Secondly, as the range of log lengths analysed in this study was relatively small, ranging from 3 metres to 5.8 metres, the difference in the number of gaps on the debarking line will also be small. If there was a larger range of log lengths (from 3 metres to 12 metres for example) passing through the debarker the difference in the number of gaps, in a given timeframe, may be significant enough to impact debarking rates.

Another factor that may be important for debarking operations is the increasing proportion of mechanised harvesting crews in the forestry industry. The significance of this is that mechanised harvesting operations result in greater proportion of bark removal than motor manual crews. As the proportion of mechanisation increases it is likely that the proportion of bark remaining on logs by the time they reach the port will decrease. This will impact debarking operations as there will be a reduction in the volume of bark that will require disposal, as well as decrease freight rate savings due to a reduced weight saving resulting from bark removal.

6.1 Limitations

There are several limitations regarding the results of this study. Firstly, it has been assumed that the proportion of log grades carted into Marsden Point by PFP will be representative of the log grades carted in by other exporters. If this is not the case then the possible debarking production mixes will differ; resulting in changes in plant capacity and subsequently debarking rates. Additionally, it has been assumed that the proportion of log grades will remain constant in future years.

A major limitation of this study is that the forecast available export volumes have been based on the 2014 Northland WAF and the average volume of domestic processing in Northland from 2012 to 2016.

It is very unlikely that the actual volume harvested will follow the 2014 WAF scenario. This is because small-scale forest owners may delay their harvest until a time where log prices are favourable; and because the short term harvesting intentions and long term strategies of large-scale owners may differ from what has been previously indicated.

Any changes in the volume of wood processed in Northland would be inversely correlated with forecasted export volumes. Changes in the volume of wood processed would also influence the volume available by log grade for exports; which will result in different debarker production mixes and consequently a different plant capacity and debarking rate.

If the assumption that 70% of the volume headed out of Marsden Point will be loaded as deck cargo is incorrect there could be large implications for the results of this study. If the assumption is an overestimation then a smaller proportion of K-Grade logs would be included in the production mix, which may increase or reduce the average debarking rate depending on the scales of economy lost. If this assumption is an underestimation then it may not be possible to debark all deck cargo outbound from Marsden Point using a Nicholoson A5C debarker.

As it is an operational requirement for debarking operations to only include logs with good geometry in the production mix, it will result with logs with bad geometry having to be stowed below deck. Because it will not be possible to stack logs with bad geometry as efficiently as logs with good geometry this could potentially result in a reduction of vessel stow factors. Accordingly, reductions in stow factor could have an influence on shipping rates. The potential impact of reduced stow factors has not been evaluated in this study due to data requirements. As such, further research may be needed to assess the impact of log mixes on vessel stowage factors.

7. Conclusion

Of all New Zealand's log exports, 99% of the total volume is destined to four markets: China (68%), Korea (17%), India (11%), and Japan (3%). Current log exporting operations out of Marsden Point use a combination of treatment methods to meet the phytosanitary standards set by importing countries. All logs stowed in a vessels hold are treated with either methyl bromide or with phosphine. The majority of logs loaded onto a ships deck are treated with methyl bromide and a small proportion is debarked.

If it is not possible to meet the requirement set by the Environmental Protection Authority to recapture or destroy all methyl bromide used for fumigation purposes, from 2020 onwards, there could be serious disruptions for some log export markets. Log exporting operations to Japan and Korea should continue as usual because phytosanitary treatments are performed by the customer once cargo reaches the importing country. Conversely, all exports to Indian markets would have to cease under the current phytosanitary rules which requires that logs must be fumigated with methyl bromide or subjected to heat treatment. Despite heat treatment being an approved phytosanitary treatment there are currently no technically viable systems to treat logs on such a large scale. For Chinese markets, methyl bromide is used to fumigate all deck cargo that has not been debarked, whilst hold cargo is treated with phosphine. As such, if the volume being fumigated with methyl bromide could be debarked then exporting operations to China could continue with minimal disruptions.

There are several factors which affect the cost of debarking export logs at a scale appropriate to export operations at Marsden Point. The main operational requirement for a debarking plant is the necessity to produce a product that meets phytosanitary standards whilst causing minimal damage to the logs. The standards in place for Chinese markets require that no more than 5% bark by volume remains on any individual log, and that no more than 2% bark remains for an entire consignment. The use of a high speed ring debarker has been identified as the best method to meet phytosanitary standards while causing minimal log damage, whilst allowing high annual throughput volumes. In order for logs to meet phytosanitary standards in a single pass through the debarker it is imperative that only logs with good geometry (Pruned, Small-Pruned, A-Grade, A-Oversize and K-Grade logs) are included in the production mix.

It was found that if all suitable log grades are included in the production mix that 71.3% of the volume carted into Marsden Point could possibly be debarked. Based on the 2014 Northland Wood Availability Forecasts and the average volume domestically processed from 2012 to 2016 it is projected that 1,372,000m^3 of wood will be available for exporting each year from 2020 onwards. Using the proportion of log grades carted into Marsden Point by PFP in 2016, and associated JAS m^3 to m^3 conversion rates, it is estimated that the annual export volume will be 1,382,772 JAS m^3.

As Mardsen Point is predominantly used for topping up vessels with deck cargo it has been assumed that 70% of the available volume will be loaded out as deck cargo. Given this assumption, approximately 967,940 JAS m^3 will be exported as deck cargo. Using the average piece size and length for all suitable log grades carted into Marsden Point, in 2016, the capacity for a Nicholoson A5C 27" debarker has been estimated at 977,000 JAS m^3 per year; indicating that all deck cargo could potentially be debarked.

The average unit cost for debarking all deck cargo has been calculated at \$2.52/JAS m^3. Additional handling costs were found to be the largest factor influencing debarking rate, accounting for 71% of the average cost. The cost of capital was the next most influential factor, accounting for 16% of costs, followed by plant maintenance which contributed 11% to overall costs. The shipping load improvements from bark removal were found to correspond to a 1% saving in average freight rates, which in turn reduced average debarking costs by 10%. Staffing and power costs had a minor influence on debarking rate, accounting for 6% and 5% of the total cost respectively. Land lease costs had the smallest influence on debarking rate, only accounting for 1% of the total cost. The base case model used to model debarking rate assumed there would be no cost for bark disposal; however, if a cost of \$20/m^3 for bark disposal was to be imposed this would have a significant influence on the average debarking rate increasing 37% to \$3.46/JAS m^3. Similarly, if a premium of \$20/m^3 was paid for bark costs would decrease 37% to \$1.59/JAS m^3.

Debarking rate was also found to vary by log grade, with the weighted average cost for debarking Pruned and A-Oversize logs estimated at \$1.09/JAS m^3, A-Grade and Small-Pruned 168% higher at \$1.84/JAS m^3, and K-Grade costing 353% more at \$3.86/JAS m^3. Debarking rate was also very sensitive to throughput volume. For example, if only Chinese bound deck cargo (approximately 70% of total deck cargo) was to be debarked then the average debarking rate would increase from \$2.52/JAS m^3 to \$2.88/JAS m^3 due to reduced economies of scale.

On average, each vessel loaded out of Marsden Point, in 2015 and 2016, was found to have over-fumigated the required deck cargo volume by 121%. After accounting for the influence of over-fumigation and rebasing costs to June 2017 dollars the true cost of methyl bromide fumigated was found to be \$5.25/JAS m^3. Based on these results it appears that debarking would be an economically favourable method for meeting phytosanitary requirements compared to methyl bromide fumigation.

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